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BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Ground-Based Flight Control Activities During Manned Space Flight Missions
Case 900

DATE: December 31, 1968

FROM: J. E. Johnson
H. Kraus

ABSTRACT

This memorandum describes the functions and activities of ground-based flight control during manned space flight missions. The memorandum contains an introduction to the concept of flight control and a brief review of its evolution, a description of the decision logic used, flight control functions and activities during a nominal mission, and a review of flight control actions during past missions through Apollo 5 when non-nominal conditions were encountered.

It is concluded that need for a significant amount of ground-based flight control will continue to exist because of the research and development nature of manned space flight missions and the limitations of both space vehicle instrumentation and crew work load.

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MEMORANDUM FOR FILE

1.0 Introduction

This memorandum describes the functions and activities of ground-based flight control during manned spaceflight missions, and reviews flight control participation in the handling of non-nominal flight conditions which have occurred during past missions.

The first section of this memorandum presents the concept of flight control, briefly reviews its evolution, and describes the flight control function and the ground support systems used in its implementation. The second section describes flight control decision logic. The third section describes flight control activities during the nominal mission. The fourth section is a review of actions taken by flight controllers to handle non-nominal conditions during past missions. The last section is a summary.

2.0 Description of Flight Control

Flight control is defined in this memorandum as the real-time monitoring, evaluation, and direction of mission progress during the flight phase. Flight control is instituted and exercised to direct flight progress towards the achievement of predetermined mission objectives. At the beginning of the manned space flight program, it was recognized that ground-based control of flights would be necessary in a major degree because of the uncertainties of space flight, particularly with regard to man's ability to survive and function in space. The early flights of the Mercury Project demonstrated that man was capable of surviving and of functioning effectively in space. Once this capability was shown, the objectives set for succeeding flights became more sophisticated and more demanding on the space vehicle and crew. Limitations of space vehicle systems precluded the on-board satisfaction of all nominal and contingency mission requirements; also, the workload imposed on the crew was found to be excessive. Thus, as the Manned Space Flight Program progressed, the need for ground-based support was increased rather than diminished.

All of the manned space flight missions to date have been of a research and development nature. Each has had the purpose of achieving specific flight objectives. Although the crew has been accorded a greater degree of freedom in conducting flight operations, these operations had to be performed within a specified mission framework to insure the achievement of the flight objectives. One of the functions of ground-based flight control is to monitor the actions of the crew and to provide back-up and support to permit the crew to perform its necessary operations. Should some malfunction or non-nominal condition occur during the flight which would prevent the achievement of some or all of the planned mission objectives, flight control directs the use of pre-planned alternative actions designed to salvage as many of the initial mission objectives as feasible. For those cases where pre-planned alternative operations are not sufficient to compensate for the conditions encountered, flight control generates new activities or modifies mission objectives to those which can be achieved under the existing conditions. If conditions violate mission safety limits, flight control can request the crew to terminate the mission. If there is no contact between flight control and the crew at that time, the crew can terminate the mission should conditions warrant such action.

Although the emphasis in this memorandum is on ground-based flight control activities as performed during the flight phase of a mission, flight control also contributes heavily to other phases of the mission. During the pre-flight phase, flight control is active in the mission design and formulation of objectives. Necessary documentation such as the mission rules (outline of pre-planned actions to assist in making real-time decisions during pre-launch, flight, and recovery phases) and the flight plan (timeline sequence of nominal mission events and activities) are generated by both the crew and flight control during the pre-flight phase. During the post-flight phase, flight control is active in the analysis of mission results and evaluation of the rules and procedures used for that mission. This activity is of particular importance in the planning of subsequent missions.

The Ground Operational Support System (GOSS) provides flight control with the facilities necessary to monitor and direct mission progress during the flight. These support systems include:

a. Manned Space Flight Network (MSFN) - The MSFN consists of a world-wide complex of communication and tracking stations which permit contact between the space vehicle and Earth. The MSFN includes ground-based stations, ship stations, and airborne stations.

b. Mission Control Center (MCC) - Flight control is effected from the MCC. The MCC provides data processing, display, and communications facilities for the flight control personnel. Flight operations are directed from a Mission Operations Control Room (MOCR). Support for the primary flight control personnel in the MOCR is provided by additional personnel in Staff Support Rooms (SSR's) adjacent to the MOCR.

c. Launch Complex - The launch complex consists of pre-launch checkout facilities, space vehicle mating and servicing facilities, launching pads, control rooms, and related instrumentation and communications.

d. Point-to-Point Ground Communications - A portion of the world-wide NASA Communications System (NASCOM) supports manned space flights by providing point-to-point ground communications between the MSFN stations and the MCC. The Godard Space Flight Center (GSFC) operates NASCOM and provides voice and data switching between the MCC and MSFN. During prelaunch and launch, a separate launch data system is provided between the MCC and the launch complex.

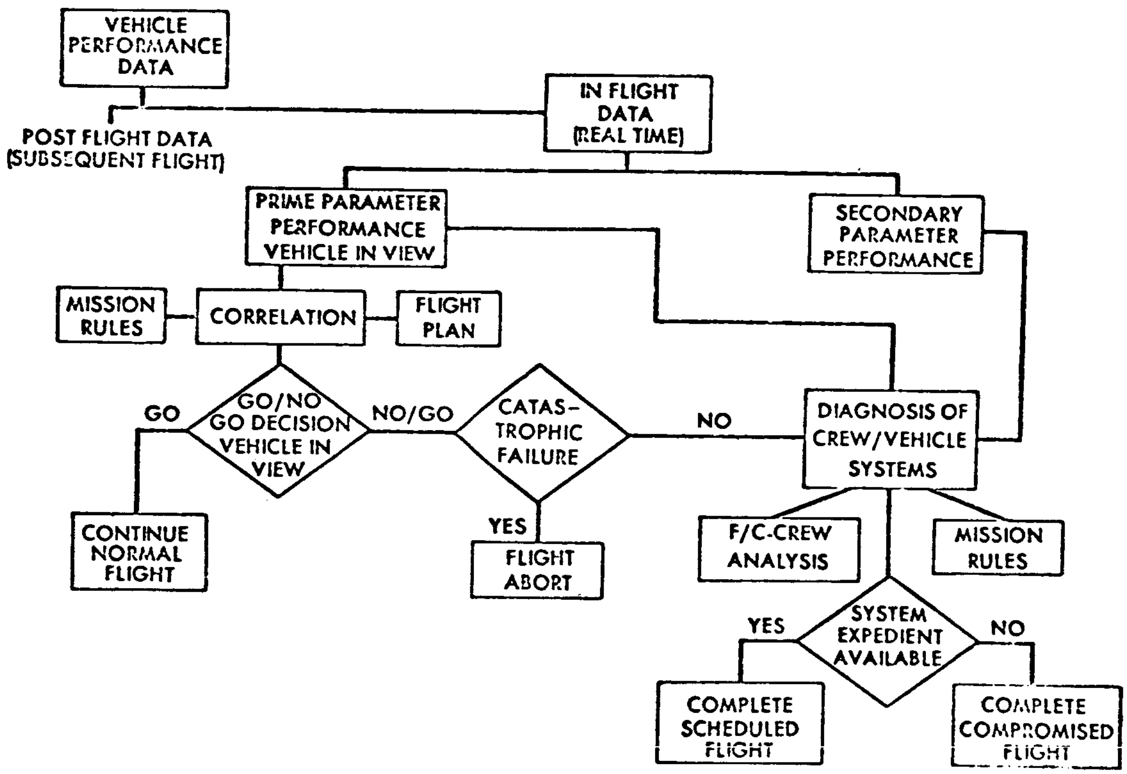
e. Network Support Team (NST) Facility - GSFC operates a Network Support Team facility located at GSFC to manage the operation of the MSFN stations during a mission.

f. Huntsville Operations Support Center (HOSC) - The Marshall Space Flight Center (MSFC) operates the Huntsville Operations Support Center. The HOSC provides the launch complex and MCC with specialist support in launch vehicle operations.

3.0 The Flight Control Decision Process

Flight control activity varies with mission progress. As long as a flight is nominal, flight control activities consist of monitoring mission progress and assisting the crew with the flight plan. For safety purposes, flight control renders a GO/NO-GO decision prior to entering critical phases of a mission. These decisions are based upon criteria established by the mission rules. The decision logic followed by flight control is diagramed in Figure 1. Data inputs from the space vehicle are separated into two categories: (1) parameters which affect the health and safety of the crew are designated prime parameters, and (2) other parameters which affect the achievement of mission objectives are designated secondary parameters. The real-time measured performance of the prime parameters together with the parameter history is correlated with criteria contained in the mission rules and flight plan. If a good correlation exists, normal flight is continued. If there is not a good correlation, the measured performance is examined to determine if a potentially catastrophic condition exists. If so, flight abort actions are initiated in accordance with the mission rules. If the condition is of a non-catastrophic nature, it is subjected to further diagnosis. Other prime parameters, applicable secondary parameters, mission rules, and inputs from both the crew and flight control are used in the diagnosis. If it is found that an option (system expedient) is available to circumvent the effects of the problem, the scheduled flight is continued using either a pre-planned alternate flight plan or a new flight plan generated in real-time.

THE LOGIC OF FLIGHT CONTROL DECISIONS



(FROM GEMINI MID-PROGRAM CONFERENCE, PART 1, REF. 19)

FIGURE 1

4.0 Flight Control Functions and Activities

Some of the functions and activities of flight control during various phases of a nominal mission are given in the following subsections.

4.1 Pre-Countdown Phase

During the pre-countdown phase, flight control provides training for flight controller and GOSS personnel. This activity also serves to verify mission rules and procedures, and the readiness of the GOSS to support the mission.

4.2 Countdown Phase

During the countdown for a single launch mission, flight control assists the launch complex in the checkout of vehicle systems. Baseline data for use during the flight is collected. A GO/NO-GO recommendation for launch is made to the launch complex during the terminal part of the count. The Launch Director at the launch complex is responsible for the final GO/NO-GO recommendation for launch. This recommendation is based upon space vehicle and GOSS readiness and recovery area weather conditions.

During the countdown for a dual launch mission, flight control provides the launch complex with target vehicle status and trajectory parameters. Recommended launch windows and launch times are computed by flight control and passed to the launch complex. Spacecraft instructions to permit rendezvous with the target vehicle at the desired time and location are computed and transmitted to the spacecraft computer and crew.

4.3 Launch Phase

Flight control assumes control of the flight following liftoff. Performance and status of space vehicle systems and crew, and launch vehicle dynamics are closely monitored. Trajectory parameters and predicted impact point(s) are computed and tested against acceptable limits. Timing and sequencing of launch events such as staging, jettison of launch escape tower, etc. are monitored. Continuous voice contact with the crew is maintained and the crew is kept apprised of the monitored flight conditions and flight progress.

For manned flights, manual abort actions during the launch phase can only be initiated by the crew or the Range Safety Officer. Flight control can only recommend or request abort action. During unmanned flights, flight control and the

Range Safety Officer have the capability of manually initiating abort. Automatic abort actions can be initiated during either manned or unmanned flight by an onboard Emergency Detection System which reacts to space vehicle sensor information. Where a number of abort modes are available, the mode selected is contingent upon flight progress and mission rules criteria.

At the end of the launch phase (insertion into Earth orbit) flight control renders a GO/NO-GO decision for orbit based upon space vehicle trajectory and systems status, and on crew status in accordance with criteria specified in the mission rules. Recovery forces and the MSFN are updated on mission progress.

4.4 Orbit Phase

When in contact with the space vehicle, flight control receives real-time information via the MSFN. The trajectory and the status and performance of the space vehicle systems and crew are determined and compared with the baseline data and past history to obtain a measure of flight progress. Assistance is provided to the crew in the evaluation and check-out of space vehicle systems in orbit. Maneuver parameters and retrofire times for planned recovery areas are computed and transmitted to the crew, spacecraft computer, recovery forces, and the MSFN. After evaluating mission progress using the latest data available, flight control renders a GO/NO-GO decision prior to initiating succeeding mission segments requiring major new commitments.

Throughout the mission, flight control uses collected data to refine computed values and to establish trends for the more significant parameters. Flight progress is carefully reviewed and evaluated. Data to be transmitted to the space vehicle is prepared, verified and disseminated to selected MSFN stations in preparation for transmission to the space vehicle during a contact period.

Should some anomaly be detected during the mission, flight control can enlist the aid of teams of specialists for the affected system(s) to analyze the problem and its effect on the course of the mission. Using the recommendations of the specialist teams and inputs from the spacecraft crew, flight control renders decisions on the course of the remainder of the flight. If the anomaly is potentially catastrophic, flight control will request the crew to terminate the flight at some planned recovery area. If the anomaly is not potentially catastrophic, flight control will select either a pre-planned alternative mission or will generate a new flight plan for the remainder of the mission in real-time.

4.5 Critical Mission Phases

Some mission phases are considered critical from both a crew safety and a mission success point of view. These phases include rendezvous with another vehicle, docking with another vehicle, extravehicular astronaut (EVA) activities, and major propulsive maneuvers. Flight control directs and assists the crew during such critical phases. Flight control is generally in a better position than the crew to assess the risks associated with these operations because it is likely to have more detailed knowledge of the status and performance of the systems of the space vehicle, more precise trajectory information, and access to a larger and more versatile data processing system.

The following are examples:

a. Rendezvous with another vehicle - From trajectory measurements on both vehicles, flight control can compute the maneuver(s) necessary to achieve the desired rendezvous in an optimum manner.

b. Docking with another vehicle - Having contact with both vehicles enables flight control to determine the status and performance of the systems of both vehicles and permits recommendations for docking or undocking operations.

c. Extravehicular astronaut activities - Flight control has the capability of monitoring the biomedical status of the EVA. Present spacecraft instrumentation does not provide for display on board the spacecraft of EVA biomedical data.

d. Major propulsive maneuvers - Flight control monitors the performance of the propulsion system during and/or after a propulsive maneuver, and determines the new trajectory, retrofire times, and burn parameters for planned recovery areas.

4.6 Retrofire and Reentry Phases

The last powered flight maneuver prior to reentry and recovery from an Earth orbital mission is the retrofire maneuver. This maneuver is perhaps the most critical event of the flight since the spacecraft reentry sequence requires that the propulsion module be jettisoned following the termination of the retrofire burn. This leaves the spacecraft with no major translational control capability until atmospheric reentry when the combination of the aerodynamic lift vector of the spacecraft and the attitude control system (used to orient the lift vector) provide some degree of cross-range and down-range control.

Flight control computes the retrofire time, burn parameters, and reentry profile (spacecraft lift vector orientation versus time) for the selected recovery area and touchdown location. This update information is transmitted to the crew, computer, recovery forces, and the MSFN. Following the termination of the retrofire burn, flight control recomputes the trajectory and corrects the reentry profile if necessary. If in contact during the reentry phase, flight control monitors reentry events. Control of the flight is relinquished to the Recovery Director following touchdown.

4.7 Summary of Nominal Functions and Activities

Throughout a mission flight control monitors and evaluates space vehicle systems and crew status and performance. Both real-time and delayed data are used in this evaluation. Trajectory parameters are computed using measurement data obtained during the flight. The computed trajectory is frequently refined to obtain a "best fit." Retrofire times and burn parameters for planned recovery areas are computed and transmitted to the spacecraft, MSFN, and recovery forces throughout the mission. Flight control renders a GO/NO-GO decision for entry into each segment of the mission requiring a major commitment of resources.

Close liaison is maintained between flight control and the crew. The crew is kept informed of monitored status and performance of space vehicle systems, weather conditions in planned recovery areas, and of mission progress. Flight control assists the crew in the analysis of non-nominal conditions, management of resources and the sequencing and conducting of experiments. Where necessary, flight control directs the crew in alternative mission plan sequences. Through this close liaison, flight control also helps to maintain crew morale.

5.0 Flight Control Actions in Past Flights

This section discusses actions taken by flight control during past flights of the Mercury, Gemini, and Apollo programs in response to non-nominal conditions. The emphasis in this section is on real-time alteration of flight plans and handling of contingency situations; however, as discussed in the previous section, flight control has many other functions that may be routine, but are highly important to the successful completion of even a nominal mission.

Some of the major problems that have occurred in past manned space flight missions through Apollo 5 are listed in Table 1 along with the resulting flight control response if applicable.

In some of these problems, flight control was not in a position to provide real-time assistance. A noteworthy example was the Gemini VIII flight. During this mission, one of the Gemini spacecraft thrusters stuck open while the spacecraft was docked with its Agena target vehicle. This set up high roll and yaw rates, which became even more pronounced after the crew separated from the Agena. All this activity happened while out of contact with flight control and the crew was on its own in attempting to bring the spacecraft under control. The crew had no direct indication of where the malfunction might be, as flight control would have had via telemetry if the space vehicle were in line of sight of an MSFN station. There had been some anomalies with the Agena reported earlier in the flight, and this may have caused the crew at first to suspect an Agena malfunction.

There have been other instances when a spacecraft was in contact with the MSFN and flight control, but the crew was in a better position to diagnose the problem and take corrective action. Instances of this nature occurred; for example, with the attitude control problem on MA-6 and the suit temperature control problem on MA-8.

The principal areas of flight control assistance in overcoming problems in manned flights to date have been in the diagnosis and correction of complex malfunctions and the real-time alteration of flight plans. Both types of assistance were well illustrated in the Gemini V flight. A fuel cell malfunction early in the planned eight day flight threatened premature termination of the mission and failure to meet most of the mission objectives. Flight control conducted extensive analyses of the fuel cell problem while the flight was in progress. They were assisted by telemetry data and a team of fuel cell experts. Although the problem was never fully clarified during the flight, enough knowledge was gained to permit continuation of the flight with confidence. As fuel cell power output gradually increased, the flight plan was revised to permit carrying out some of the planned experiments. The crew would not have been able to have diagnosed and corrected this problem by themselves since they had neither the telemetered information available to flight control nor the expertise available from the fuel cell specialists. In addition, they had a full time task in controlling the spacecraft.

Examples of real-time flight plan alteration occurred in the last four Gemini missions, every one of which deviated from the nominal in significant respects. Gemini IX-A's flight plan was altered when a shroud covering the target vehicle failed to separate in orbit. Unexpected extravehicular astronaut fatigue problems were encountered in Gemini IX-A and XI. High fuel usage during rendezvous handicapped Gemini X. Difficulty with the Agena propulsion system led to deletion of a second Agena burn during Gemini XII, and a non-preplanned astronomical experiment was substituted. All of these missions met substantailly all of their objectives, although none could be classed as nominal.

During unmanned missions, flight control capability to command the spacecraft is the only way mission objectives can be achieved if significant malfunctions occur. This happened in the MA-5 and Apollo 5 flights. During MA-5 (with the chimpanzee, Enos, on board), an attitude control problem threatened to deplete all the reaction control system fuel before the time planned for reentry. As a result, the flight was terminated one revolution early. A premature shutdown of the first burn of the descent propulsion engine on the Apollo 5 mission threatened the carrying out of the remaining programmed burns and "fire-in-the-hole" staging demonstration. Flight control transmitted back-up command sequences to the spacecraft to permit the successful completion of these events.

Appendices A, B, and C show planned and actual mission flight plans in block diagram form for Mercury flights MA-5 through MA-9, Gemini flights G-IV through G-XII, and Apollo flights 4 and 5, respectively.*

6.0 Summary

The principal functions of flight control are to evaluate and direct the progress of a mission within the framework of crew safety and mission success criteria. Current flight control concepts have evolved from Mercury to the present as a consequence of:

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*The Gemini block diagrams were taken from the individual Gemini mission reports and are generally more detailed than those for Mercury and Apollo. The Mercury and Apollo block diagrams were developed by the authors based on published data.

a. Greater information transfer capability between the space vehicle and the ground, and from point-to-point on the ground.

b. More sophisticated and more efficient computer and data processing systems on the ground and in the space vehicle.

c. Increased knowledge and confidence in man's ability to exist and to function effectively in a space environment.

d. Development of mature flight control and astronaut teams with past experience to draw upon.

This system of flight control has enabled us to fly more advanced mission sooner and with greater confidence in their success.

The present concepts of ground-based flight control will doubtless continue to be used due to the research and development nature of the missions and the space vehicles, and the limitations of the space vehicle instrumentation and the crew work load capability. In the future, if space vehicles become operational rather than R&D vehicles, it may be possible for them to operate as relatively autonomous entities in a manner similar to today's commercial aircraft with ground control and guidance being used for purposes of "traffic control." However, for the present and forseeable future, ground-based flight control is expected to provide the primary mission direction and control, although, of course, the crew has the final responsibility for actions taken on board the space vehicle.

J. E. Johnson

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H. Kraus

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TABLE I

MAJOR MISSION PROBLEMS

MISSION	NATURE OF PROBLEM	FLIGHT CONTROL RESPONSE
MERCURY		
MA-5	ATTITUDE CONTROL MALFUNCTION	TERMINATED FLIGHT EARLY
MA-6	ATTITUDE CONTROL MALFUNCTION	*
	LANDING BAG DEPLOY SIGNAL	SET UP CONTINGENCY REENTRY SEQUENCE
MA-7	EXCESSIVE FUEL CONSUMPTION	ALERTED CREW TO SITUATION
MA-8	SUIT TEMPERATURE CONTROL	*
MA-9	ELECTRICAL POWER SYSTEM MALFUNCTIONS	REVISED RETRO AND REENTRY CHECKLIST
GEMINI		
G-II	LOSS OF CONTROL CENTER POWER	*
G-IV	EXCESSIVE FUEL CONSUMPTION	ALTERED FLIGHT PLAN
G-V	SPACECRAFT COMPUTER FAILURE	*
	RENDEZVOUS EVALUATION POD	*
	POOR VECTOR DATA	ORDERED ABANDONMENT OF EXPERIMENT
	FUEL CELL MALFUNCTION	ALTERED FLIGHT PLAN, ADVISED DIAGNOSTIC AND CORRECTIVE ACTION
G-VI	LOST AGENA	*
G-VIII	STUCK OPEN THRUSTER	SELECTED CONTINGENCY LANDING AREA, SUPPLIED NECESSARY RETRO LOADS

*NO SIGNIFICANT FLIGHT CONTROL RESPONSE IN TERMS OF IMPACT ON MISSION.

MAJOR MISSION PROBLEMS (contd.)

MISSION	NATURE OF PROBLEM	FLIGHT CONTROL RESPONSE
G-IX	LOST AGENA	*
G-IXA	TARGET DOCKING ADAPTOR SHROUD FAILED TO SEPARATE	ALTERED FLIGHT PLAN
	EXTRAVEHICULAR ASTRONAUT FATIGUE, VISOR FOGGING	ALTERED FLIGHT PLAN
G-X	EXCESSIVE FUEL USAGE	ALTERED FLIGHT PLAN
	SUBSTANTIAL EXTRAVEHICULAR CURTAILMENT	*
G-XI	AGENA INSTRUMENTATION MAL-FUNCTIONS	PROVIDED ADDITIONAL DATA ON AGENA
	EXTRAVEHICULAR ASTRONAUT FATIGUE	*
G-XII	SUSPECTED AGENA PROPULSION SYSTEM MALFUNCTION	DELETED HIGH-APOGEE PHASE, SUBSTITUTED ECLIPSE PHASE
APOLLO		
A-5	PREMATURE DESCENT PROPULSION SYSTEM SHUTDOWN	ALTERED FLIGHT PLAN

*NO SIGNIFICANT FLIGHT CONTROL RESPONSE IN TERMS OF IMPACT ON MISSION.

TABLE I (continued)

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APPENDIX A

Project Mercury Flights

The flights conducted in Project Mercury are summarized below:

Designation	Launch Date	Crew	Type	Remarks
MA-1	7/29/60	Unmanned	Suborbital	Structural failure during launch. Vehicle destroyed
MA-1	11/21/60	Unmanned	Suborbital	Shut down immediately after lift-off
MR-1A	12/19/60	Unmanned	Suborbital	
MR-2	1/3/61	Chimpanzee	Suborbital	Spacecraft almost sank
MA-2	2/21/61	Unmanned	Suborbital	
MA-3	4/25/61	Unmanned	Orbital	Guidance system failure during launch. Booster destroyed, spacecraft recovered
MR-3	5/5/61	Shepard	Suborbital	
MR-4	7/21/61	Grissom	Suborbital	Spacecraft sank, astronaut recovered
MA-4	9/13/61	Unmanned	Orbital	1 rev.
MA-5	11/29/61	Chimpanzee	Orbital	3 rev. planned, 2 achieved.
MA-6	2/20/62	Glenn	Orbital	3 rev.
MA-7	5/24/62	Carpenter	Orbital	3 rev.,landing overshot
MA-8	10/3/62	Schirra	Orbital	6 rev.
MA-9	5/15/63	Cooper	Orbital	22 rev.

Block diagrams of the flight plans and actual flights for missions MA-5 through MA-9 are shown in Figures A-1 through A-5. These have been developed by the authors based on published data.

APPENDIX B

Gemini Flights

The flights conducted in the Gemini Program are summarized below:

Designation	Launch Date	Crew	Remarks
G-I	4/8/64	Unmanned	64 revs.
G-II	1/19/65	Unmanned	Suborbital
G-III	3/23/65	Grissom Young	3 revs.
G-IV	6/3/65	McDivitt White	4 days, extra-vehicular activity (EVA)
G-V	8/21/65	Cooper Conrad	8 days
G-VI	10/25/65	Schirra Stafford	Cancelled after Agena target vehicle was lost
G-VII	12/4/65	Borman Lovell	14 days Extra Vehicular Activity (EVA)
G-VIA	12/15/65	Schirra Stafford	1 day, rendezvous with G-VI
G-VIII	3/16/66	Armstrong Scott	Planned 3 day mission curtailed at 14 hours due to control system malfunctions. Rendezvous and docking achieved.
G-IX	5/17/66	Stafford Cernan	Cancelled after Agena target vehicle was lost
G-IXA	6/3/66	Stafford Cernan	3 days, rendezvous with Agena Target Docking Adaptor (ATDA), EVA
G-X	7/18/66	Young Collins	3 days, rendezvous and docking, EVA
G-XI	9/12/66	Conrad Gordon	3 days, rendezvous and docking, EVA
G-XII	11/11/66	Lovell Aldrin	4 days, rendezvous and docking, EVA

APPENDIX B

Block diagrams of the flight plans and actual flights for missions G-IV through G-XII are shown in Figures B-1 through B-9. These have been taken from the Gemini mission reports.

APPENDIX C

Apollo Flights

The Apollo flights reviewed are summarized below:

Designation	Launch Date	Crew	Remarks
AS-501 (Apollo 4)	11/9/67	Unmanned	2+ rev with S-IVB restart, CSM only
AS-204L (Apollo 5)	1/22/68	Unmanned	8 hrs., LM only, no recovery

Block diagrams of the flight plans and actual flights for missions Apollo 4 and Apollo 5 are shown in Figures C-1 and C-2. These were developed by the authors based on published data.

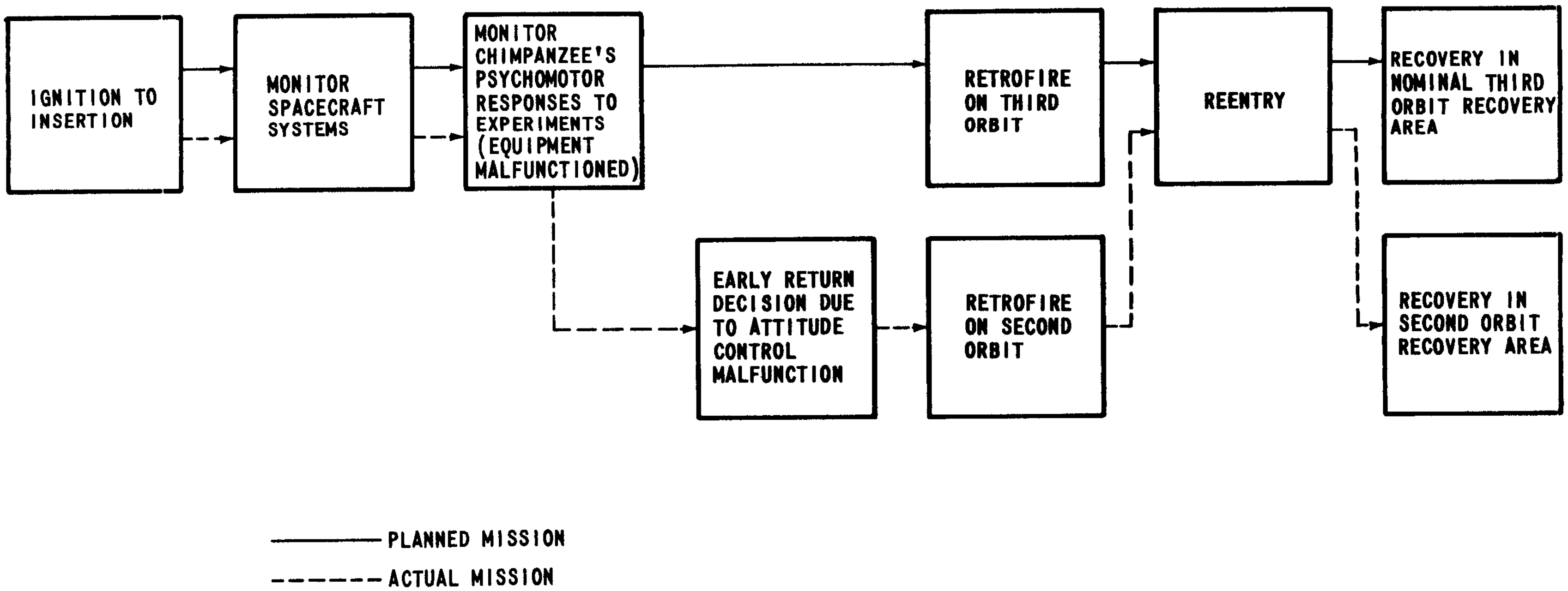


FIGURE A-1 - MA-5 (CHIMPANZEE "ENOS")

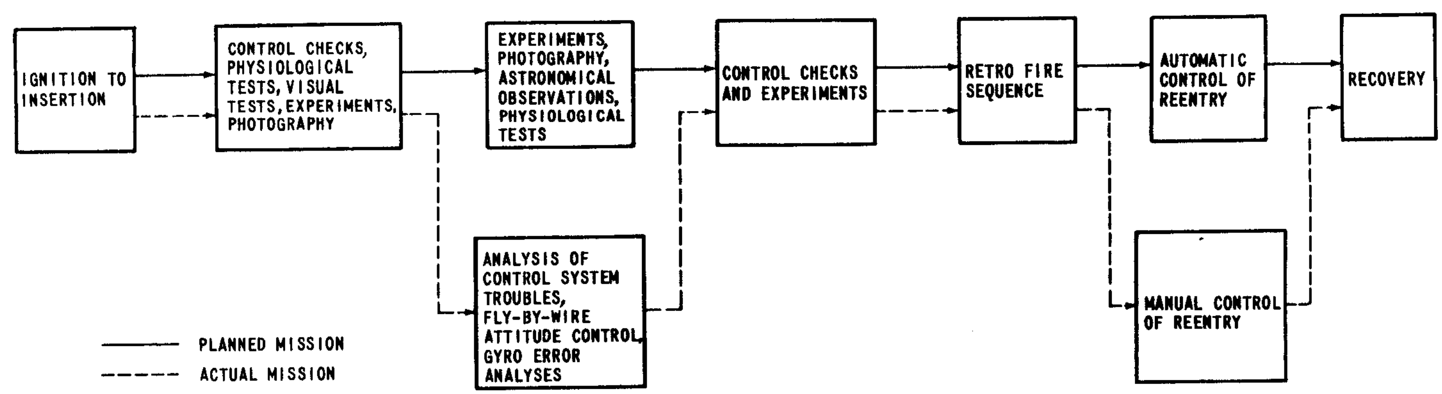


FIGURE A-2 - MA-6 (GLENN)

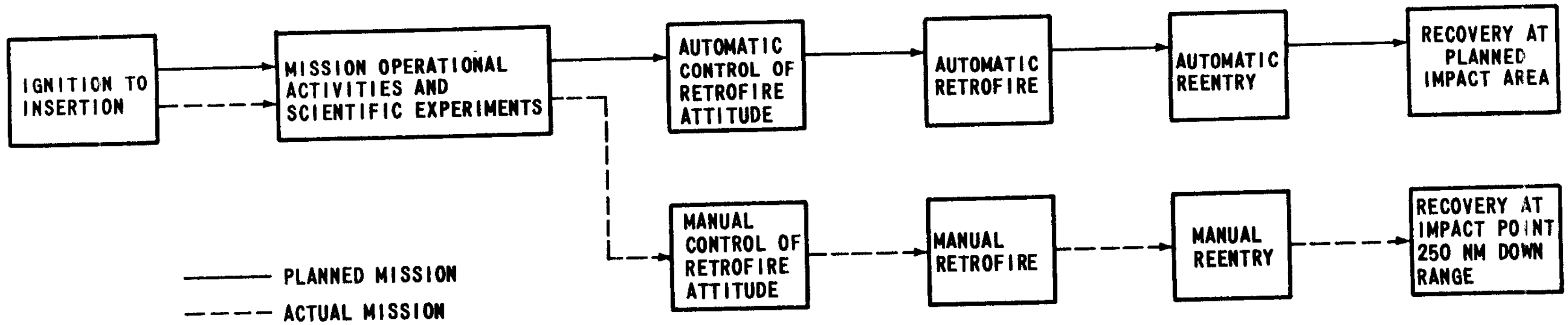


FIGURE A-3 - MA-7 (CARPENTER)

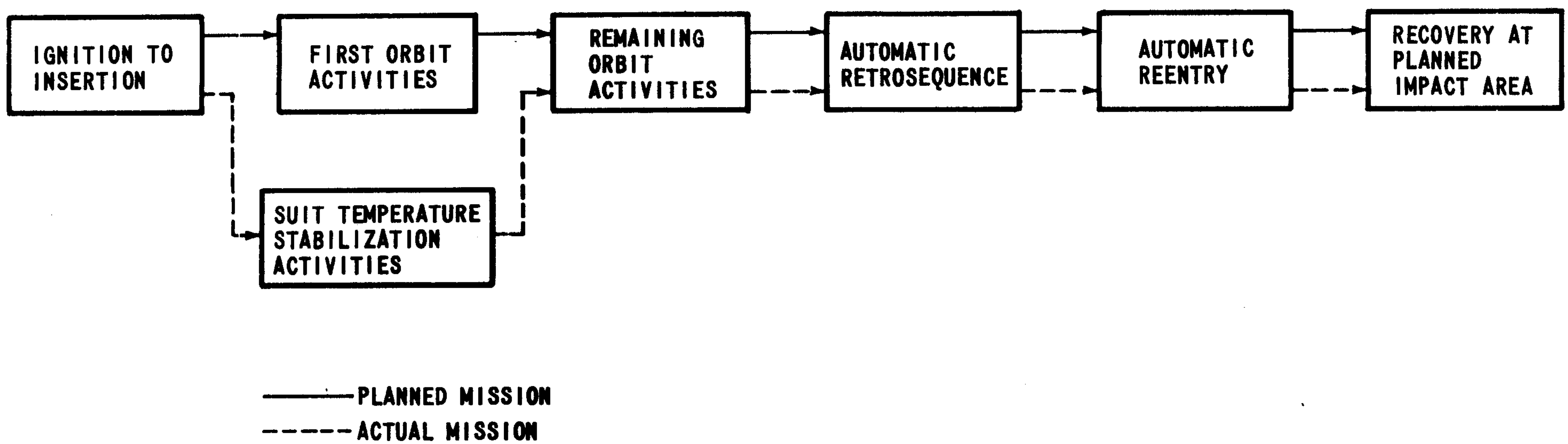


FIGURE A-4 - MA-8 (SCHIRRA)

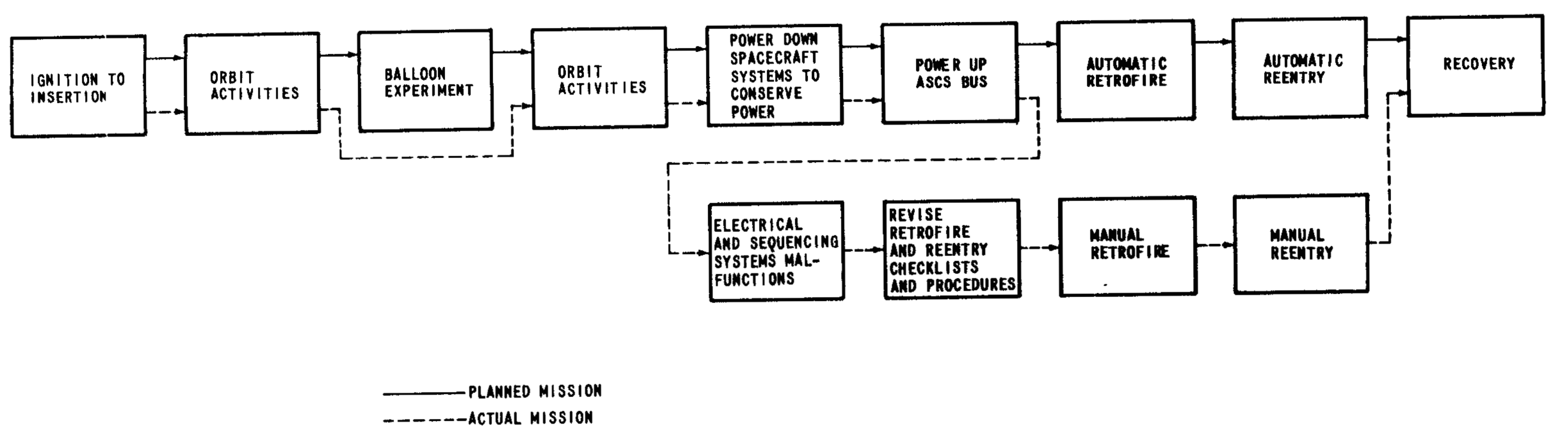


FIGURE A-5 - MA-9 (COOPER)

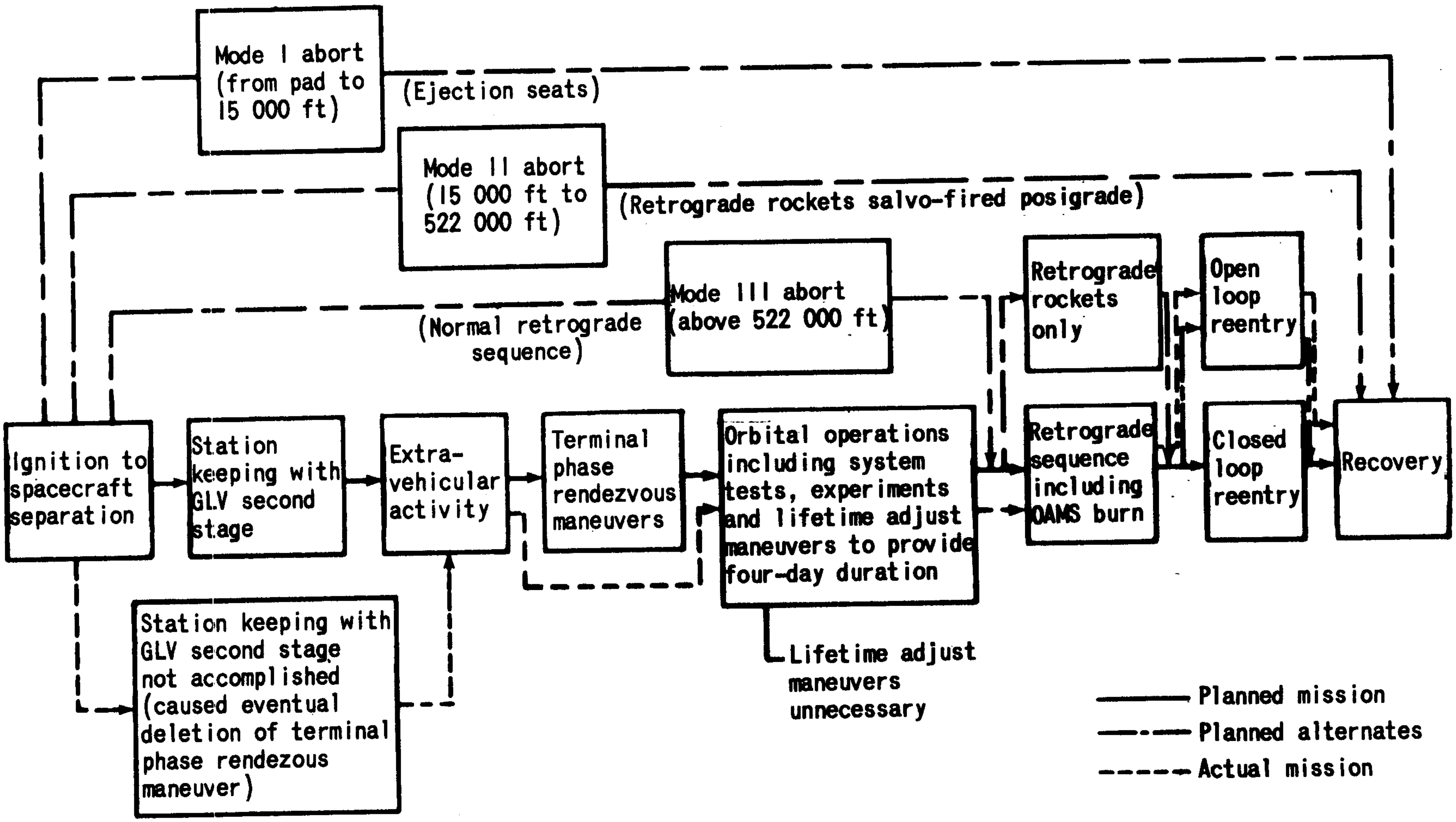
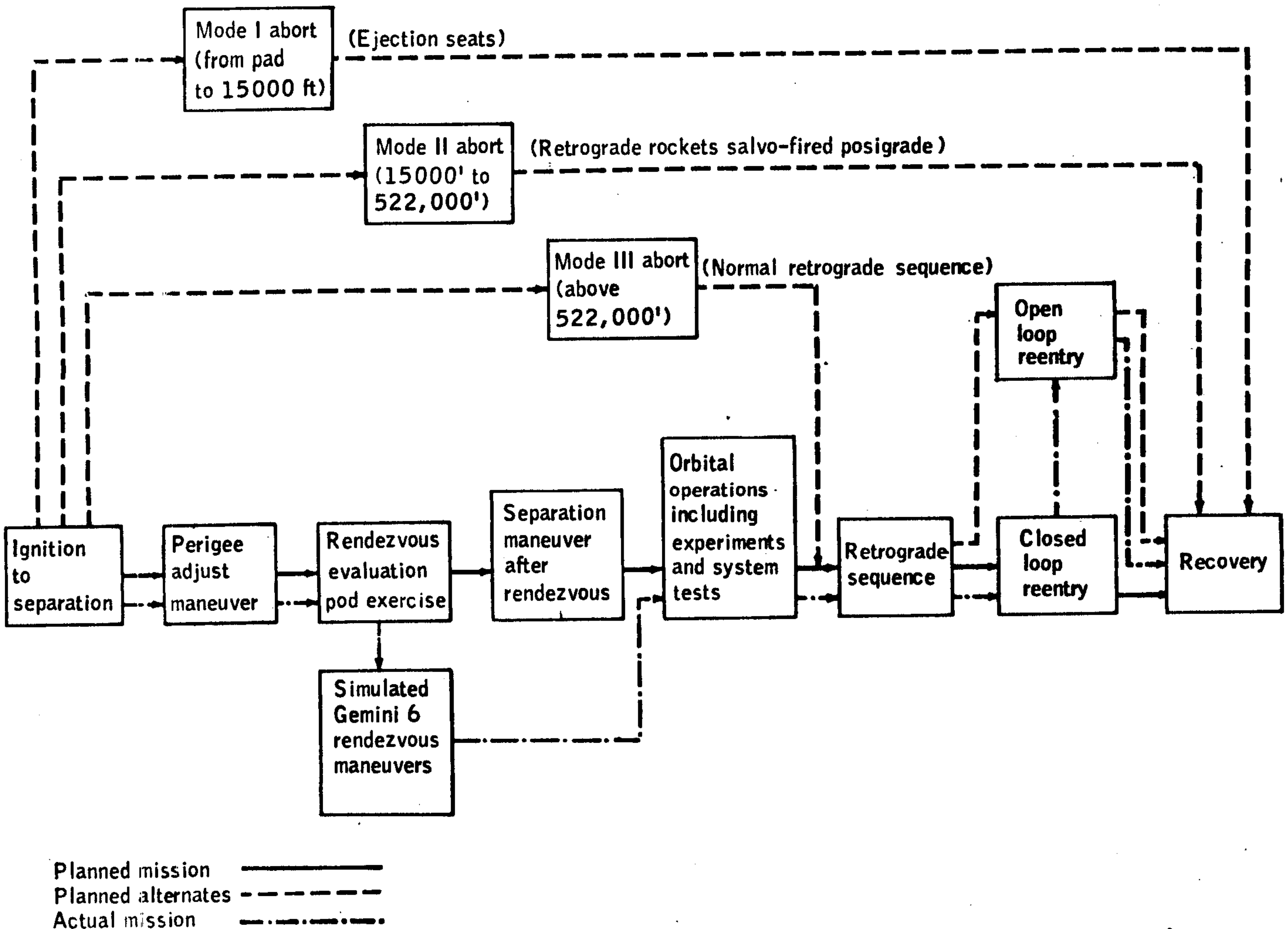


Figure B-I From Ref. 9
Gemini IV (McDivitt and White)



(FROM REF. 10)

FIGURE B-2 - GEMINI V (COOPER AND CONRAD)

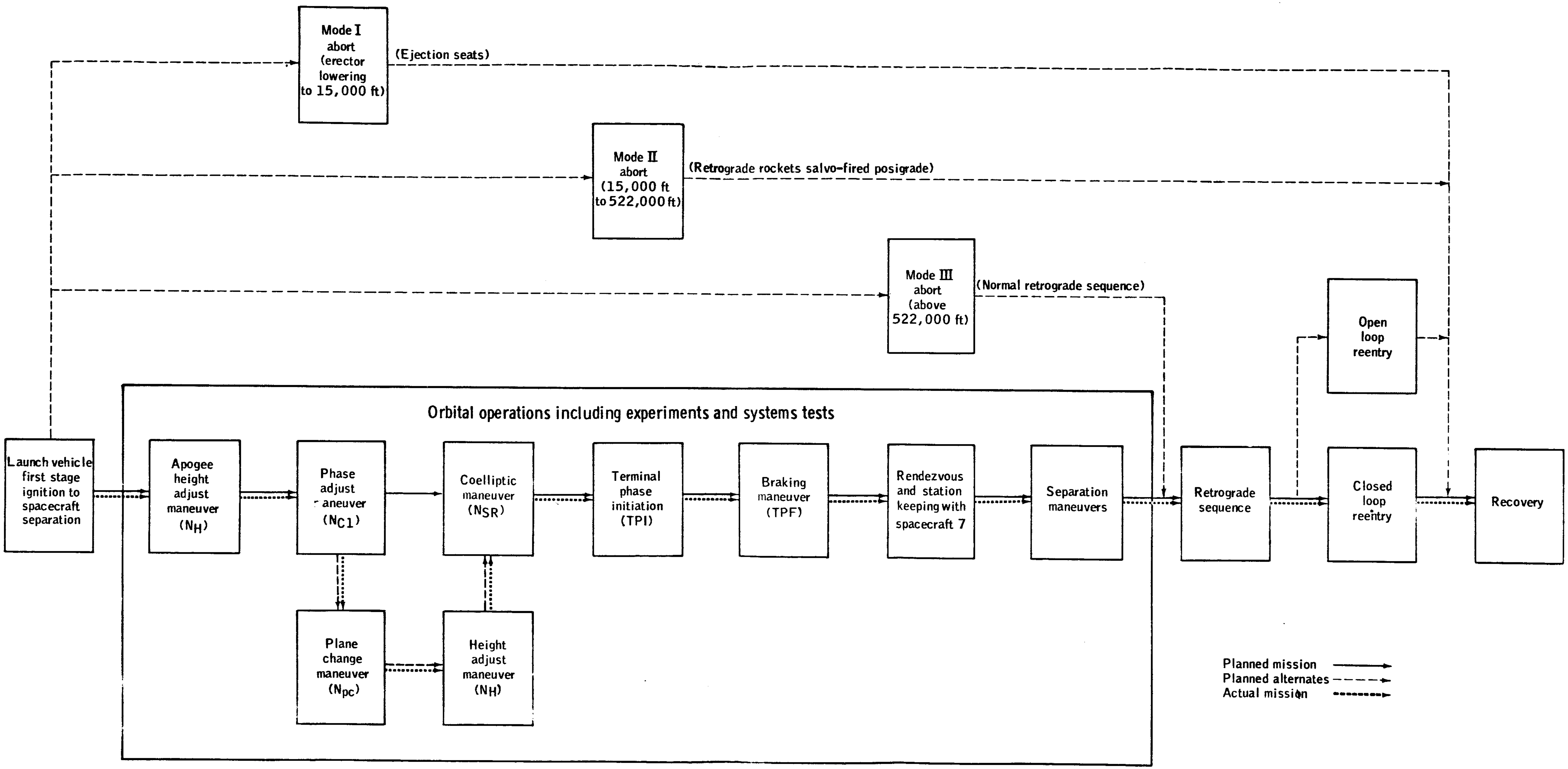
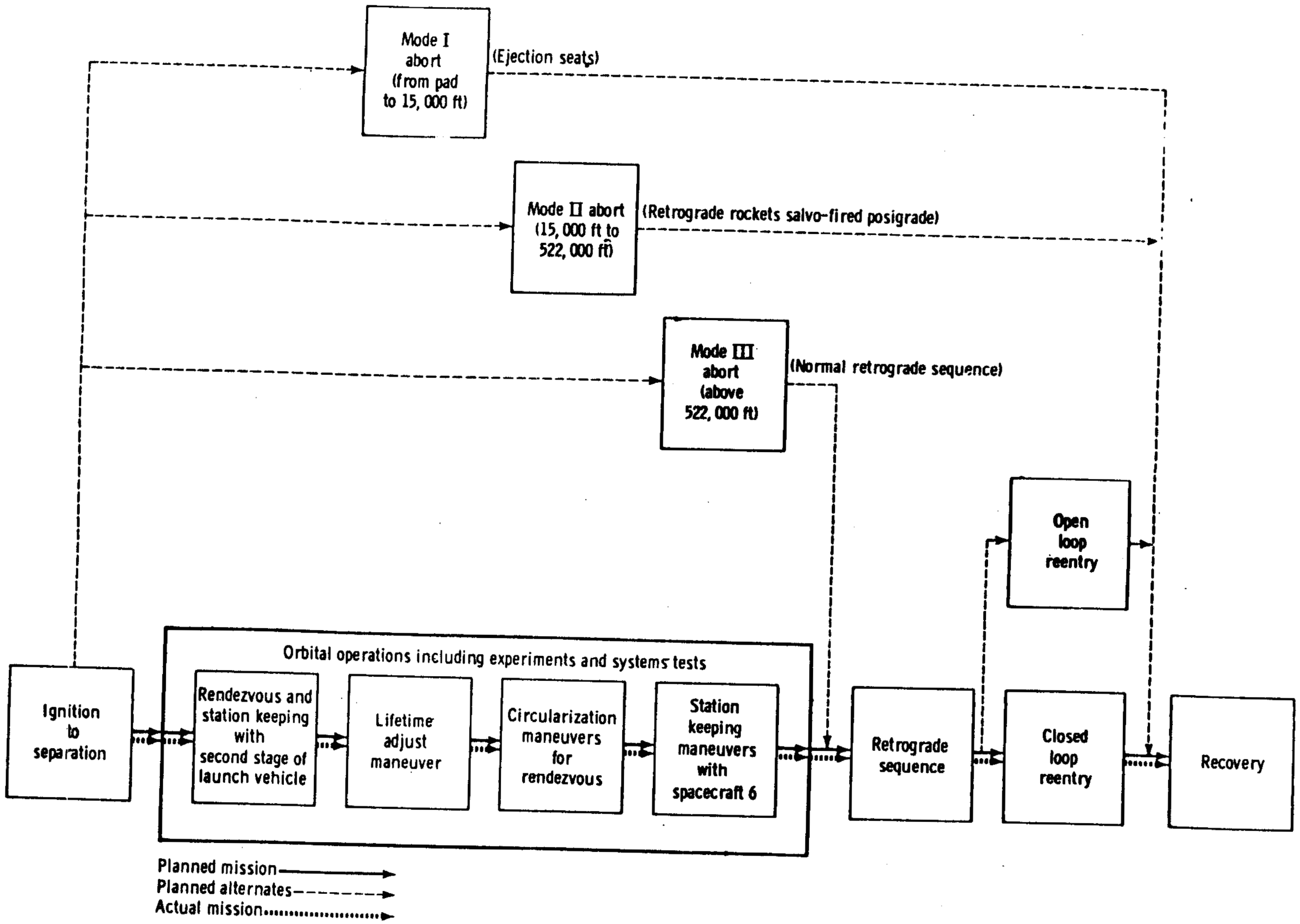
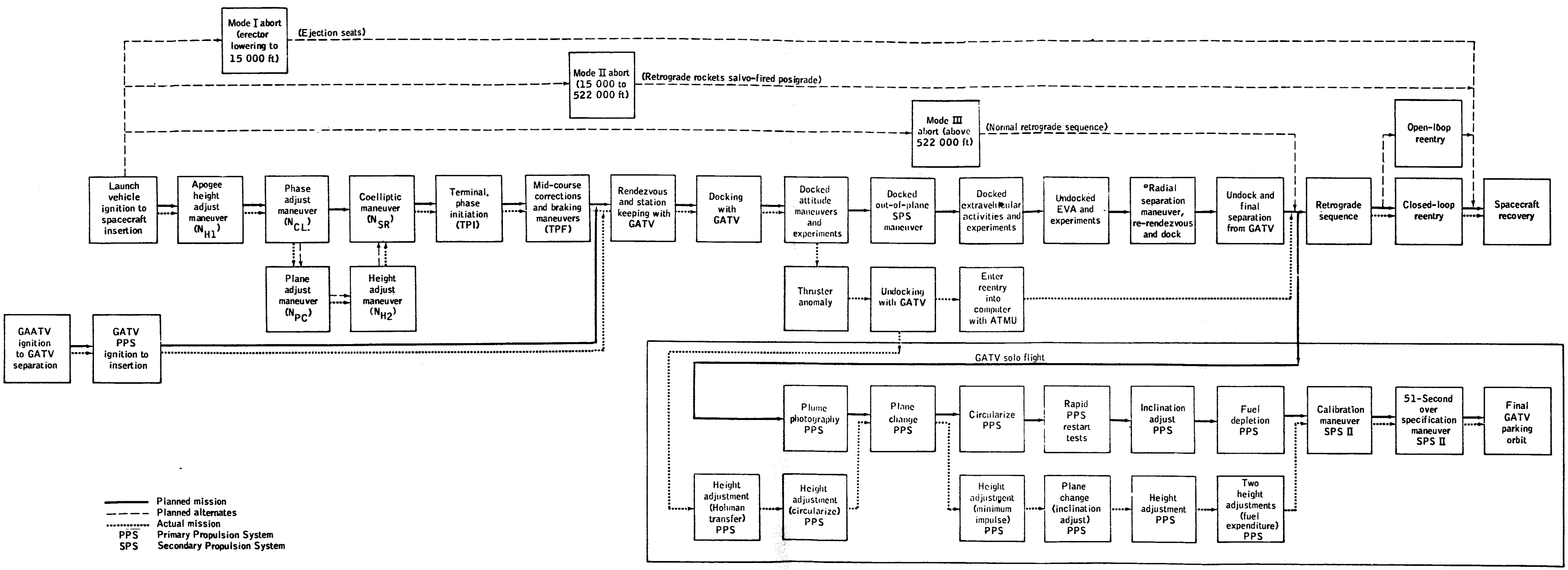


FIGURE B-3 - GEMINI VI (SCHIRRA AND STAFFORD) (FROM REF. 11)



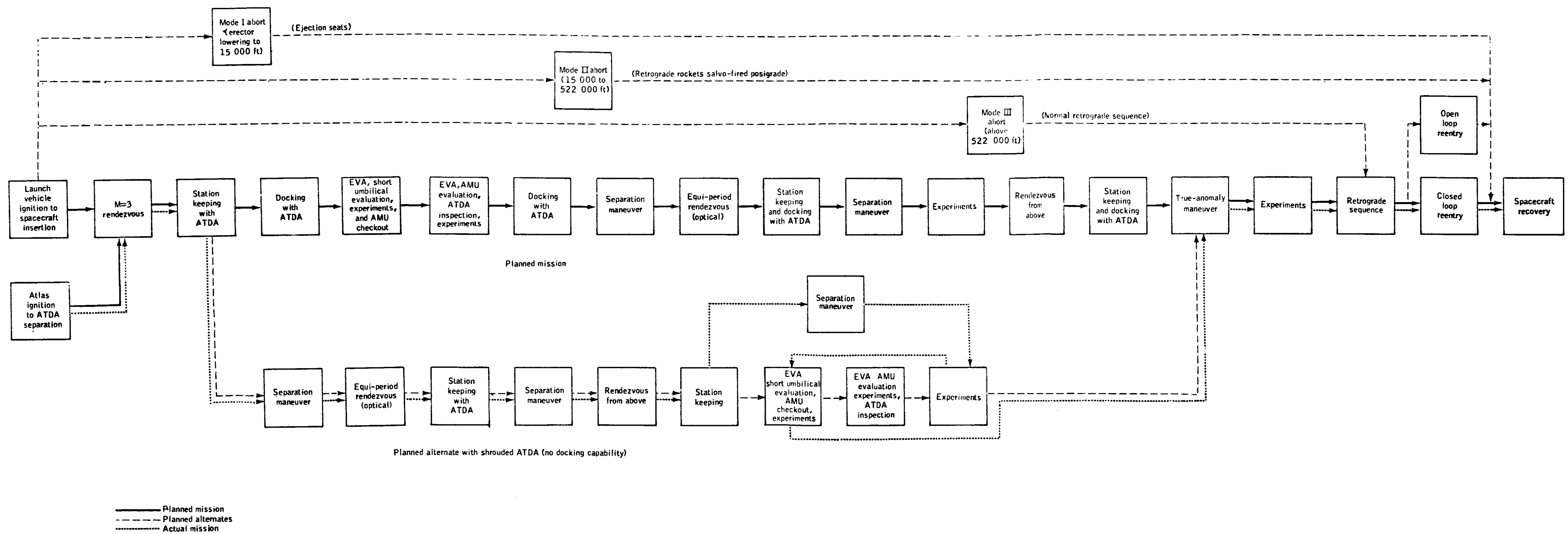
(FROM REF. 13)

FIGURE B-4 - GEMINI VII (BORMAN AND LOVELL)



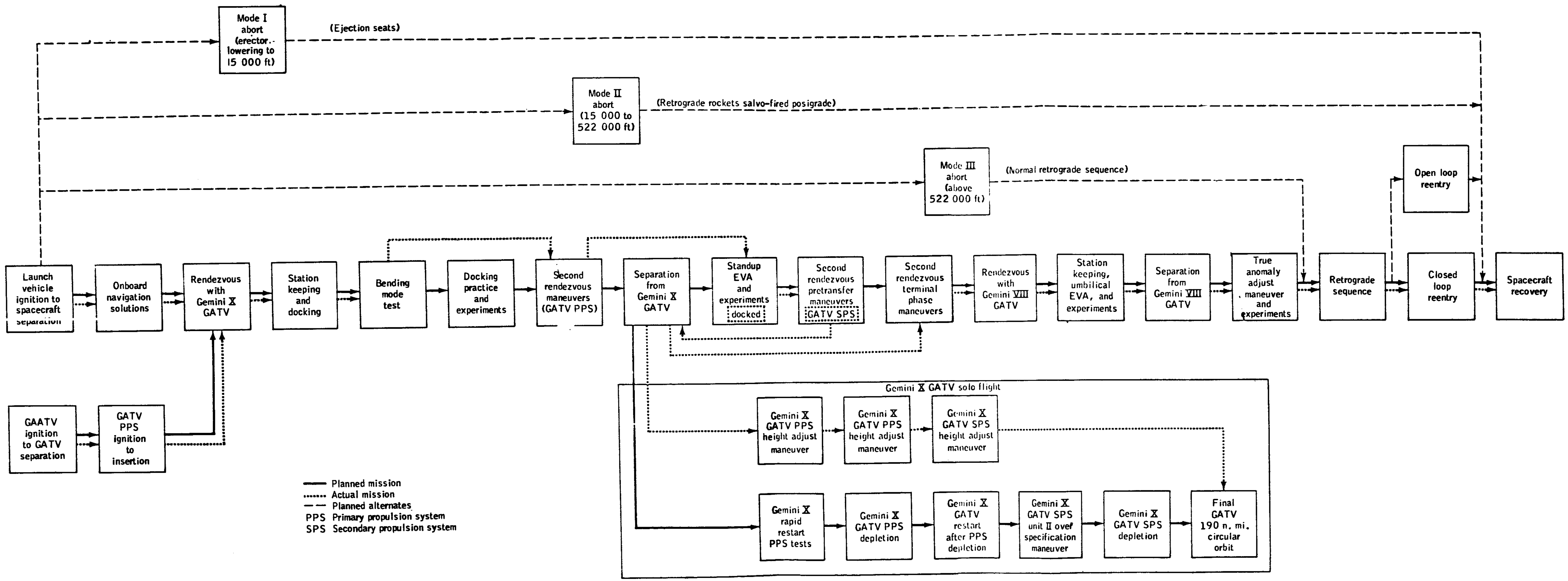
(FROM REF. 14)

FIGURE B-5 - GEMINI VIII (ARMSTRONG AND SCOTT)



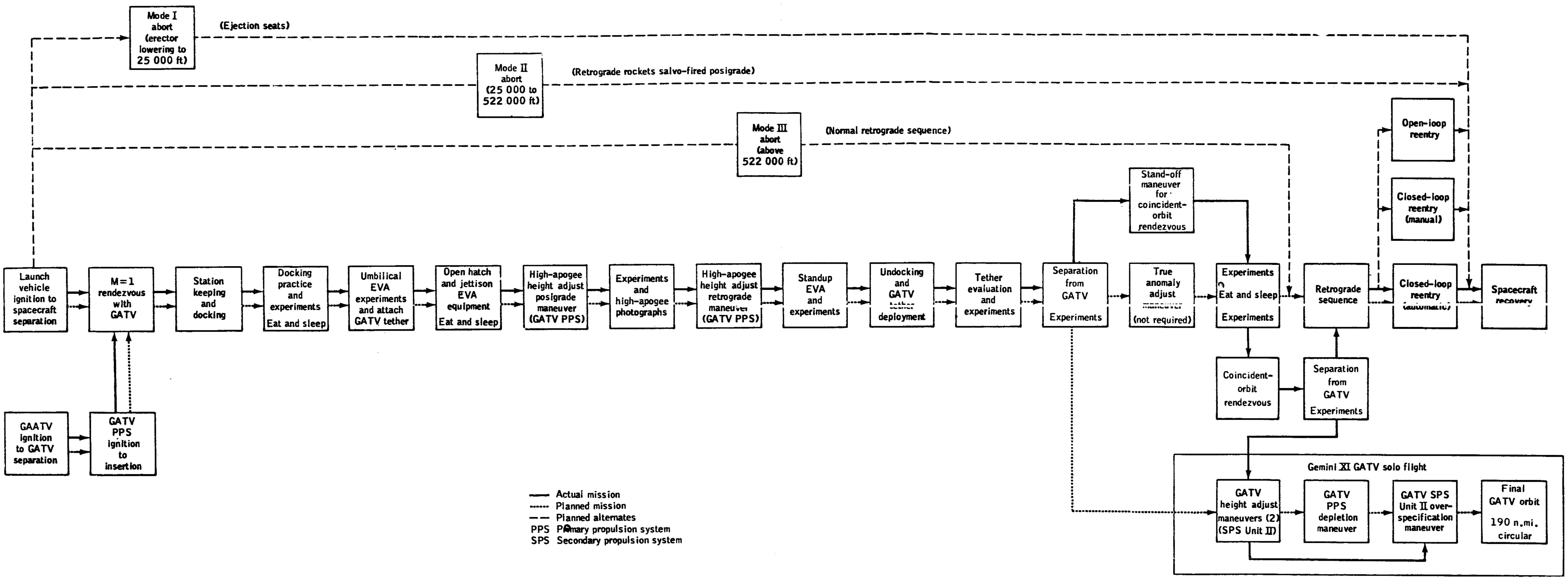
(FROM REF. 15)

FIGURE B-6 - GEMINI IX-A (STAFFORD AND CERNAN)



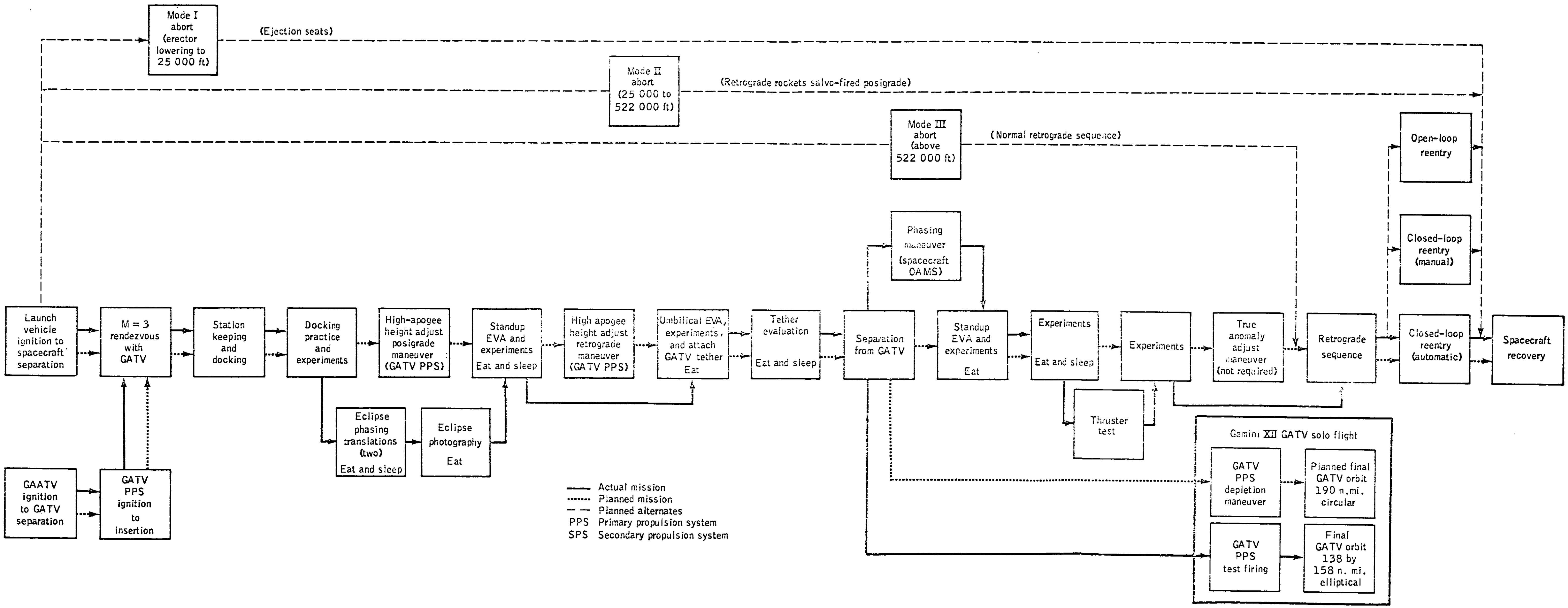
(FROM REF. 16)

FIGURE B-7 - GEMINI X (YOUNG AND COLLINS)



(FROM REF. 17)

FIGURE B-8 - GEMINI XI (CONRAD AND GORDON)



(FROM REF. 18)

FIGURE B-9 - GEMINI XII (LOVELL AND ALDRIN)

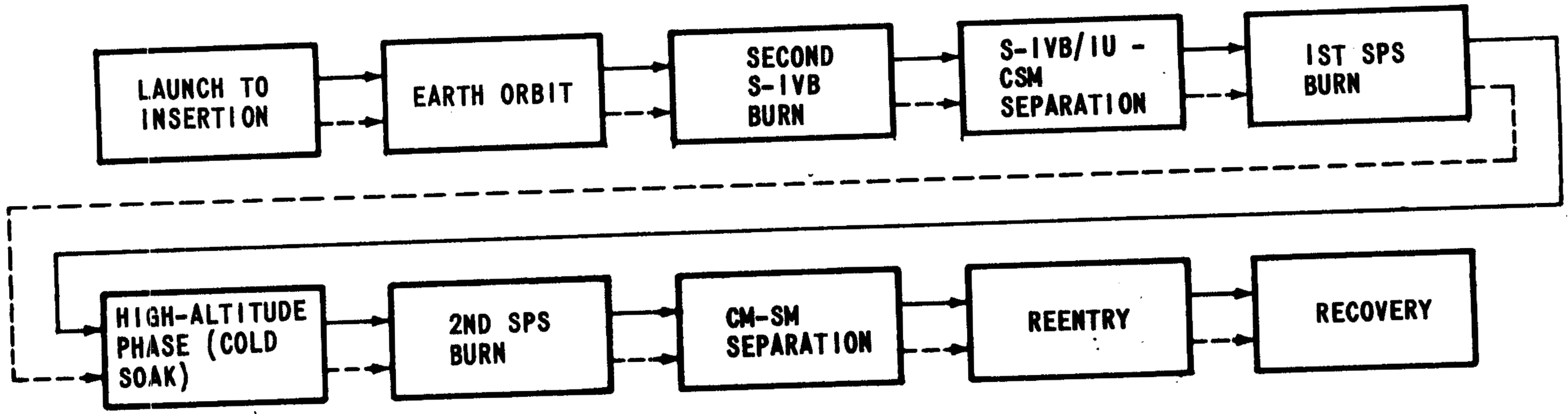
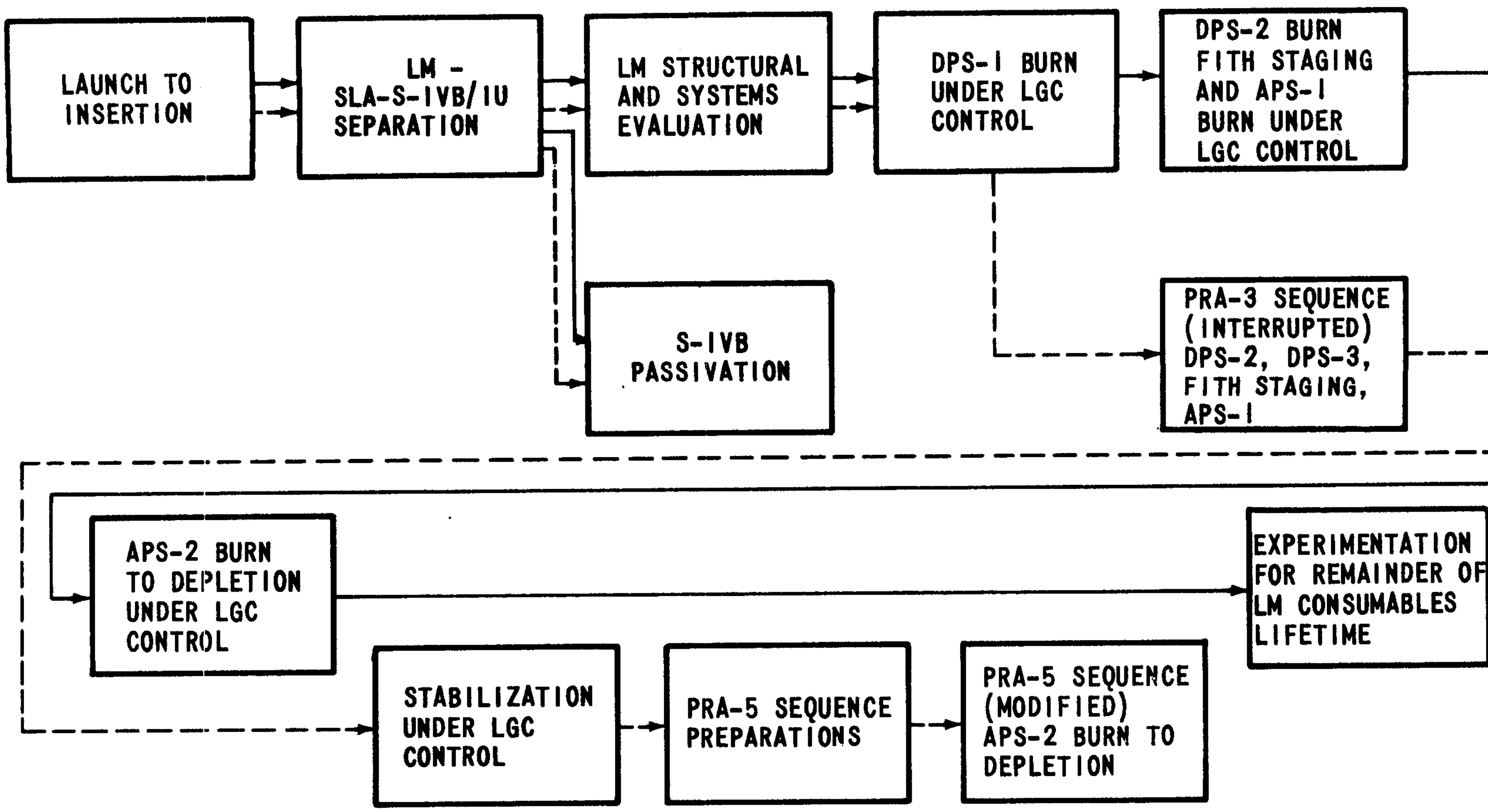


FIGURE C-I - APOLLO 4 (UNMANNED)



——— PLANNED MISSION
– – – – ACTUAL MISSION

SLA - SATURN/LM ADAPTER
DPS - DESCENT PROPULSION SYSTEM
LGC - LM GUIDANCE COMPUTER
FITH - "FIRE IN THE HOLE"
APS - ASCENT PROPULSION SYSTEM
PRA - PROGRAM READER ASSEMBLY

FIGURE C-2 - APOLLO 5 (UNMANNED)

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